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POWER SOURCE

Field of the present invention.

The present invention relates to heat activated power sources, and in particular to heat activated power sources that are suitable for use in pyro-electronic detonators. The present invention furthermore relates to pyro-electrical detonators comprising such a heat activated power source.

Technological background

When designing a blasting round, a number of blasting charges are placed according to a predetermined scheme. The scheme is designed depending on environmental parameters and on the desired blasting result. The scheme prescribes not only the position of each charge but also the amount of explosive and delay time for each charge.

Individually chosen delay times define the exact order and time sequence in which the charges are to be detonated. The delay times are typically chosen to be somewhere between nil and 9 seconds. Suitable choice of the delay times provides for more accurate blasting result. In effect, less explosive agent is needed, the blasting result can be more accurately determined, and unwanted damages to surrounding structures can be eliminated. Therefore, the delay time accuracy is crucial for successful operation.

The delay times are typically specified separately in each blasting charge before the actual detonation. The delay time specifies the time from activation to detonation for each charge such that the blasting round can be activated once and for all. Alternatively the charges can be made to detonate instantaneously upon activation. However, the latter alternative requires uninterrupted and real-time communication between a

subsequent charge and a control unit even after detonation of a previous charge, which might potentially be located close to the subsequent charge. Such communication can of course be quite problematic, and the delay times are therefore better specified in the respective detonator unit of each charge.

Safety and reliability must always come in first hand when designing blasting equipment. Unintended detonation of the explosives is of course totally unacceptable. In addition, commercial blasting equipment must withstand quite rough handling with maintained safety of operation. As a consequence, only a small fraction of the solutions and techniques otherwise used meet the exceptionally high standards put on blasting equipment.

Nonetheless there are several different designs available for detonators with delay functionality. Some of them are purely pyrotechnical, some are purely electronic, and still some are pyro-electronic. Purely pyrotechnical detonators can be made safe indeed, but the pyrotechnical reactions can only be controlled to a certain degree. In effect, the delay time accuracy is a function of the delay time duration (i.e. the accuracy of the pyrotechnical delay element used is relative to the size of the delay element). This results in reduced delay time accuracy, in particular for delay times exceeding 500 ms. Actually, analysis of the development of commercial initiation devices for civil purposes for the last 20 years shows that the accuracy of capsules with pyrotechnical delay elements have reached its limit. An example of a purely pyrotechnical system can be found in US 6227116.

As of today, delays of up to 500 ms can be achieved with an accuracy of around +/- 9 ms using pyrotechnical delay elements. For delay times between 600 ms and 1000 ms the accuracy is reduced to around +/- 12 ms. Increasing the delay time to 6 seconds is even more

problematic, resulting in an accuracy of about +/- 200 ms. Hence, the delay time accuracy in pyrotechnical systems is a function of the delay time magnitude. Increasing the delay time magnitude decreases the accuracy.

Modern methods of blasting, such as mass blasting, blasting bore holes with large diameters or expanded bases, and forming of accurate tunnel profiles, require delay times between 1 and 9 seconds or even more. Today this work is done using long delay pyrotechnical blasting capsules, which have a relatively low delay accuracy of +/- 100 ms to +/- 200 ms. Such low levels of accuracy are one of the biggest bottlenecks towards higher accuracy blasting.

Purely electronic designs use an electric cable as bus, sending an electrical signal to the detonator wherein the delay time is defined by an electronic circuitry sending an initiation signal to the detonator charge. Alternatively, a radio communication link between the control unit and detonator is established. Using electronic systems, the delay times can be set with relatively high accuracy that is virtually independent from the delay time magnitude. However, electronic detonators are related with problems in meeting the safety standards. Furthermore, operating staff needs system specific training. Switching from a pyrotechnical system to an electronic system is thus related to extensive and expensive training programs for the personnel.

Pyro-electronic detonators use a combination of pyrotechnical reactions and electrical signals. Such a system uses a pyrotechnical fuse (e.g. a shock tube) providing for high safety of operation but also for operability by personnel trained on purely pyrotechnical systems. In fact, a pyro-electronic system can be designed to operate and appear just like a purely pyrotechnical counterpart. The detonator is however

equipped with a pyro-electronic delay unit taking the pyrotechnical fuse signal as input, converting it to an electrical signal which is delayed in an electronic circuitry before initiating a pyrotechnical initiation charge. Such pyro-electronic systems are considered as very promising in the future development of increasingly better blasting systems operable by personnel trained on traditional pyrotechnical systems. Particular advantages include that accurate delay times can be controlled by an electronic circuitry, having a delay time accuracy that is virtually independent of the delay time magnitude, and that the system can be operated by personnel trained on purely pyrotechnical systems. In effect, the delay time can be made as accurate for seconds of delay as for milliseconds of delay with a system that from an operational point of view appears to be a purely pyrotechnical system.

Pyro-electronic detonators providing for up to 9 seconds delays with an accuracy of +/- 9 ms are expected to have immediate commercial application. This requirement imposes high demands on the electrical power source that converts the pyrotechnical signal to an electrical signal. Thus, the electrical power source is a crucial component for successful operation of a pyro-electronic system. Basically, the power source must be able to output electrical energy within a very short and accurate time span from being exposed to the burning fuse.

WO01/18484 proposes one possible design for a shock tube initiated power source comprising a movable battery unit. Basically, the battery unit is moved from a passive position to an active position where it connects with the electronic drive circuitry of the detonator. The movement is caused by a pyrotechnical charge that in turn is initiated by the shock tube signal. Even though the above-described system has advantages for certain applications, it is related with some problems. For

example, there is always a risk for unintended activation of the detonator by incautious handling since the battery is always operative and ready to move to the active position.

Another possible design is indicated in WO96/04522, which teaches the use of an "electrolytic power source" in a "non-electrical detonator" (which, in effect, is a pyro-electronic detonator). The "electrolytic power source" is referred to as a thermo battery that is activated by a shock tube. However, the document gives no indication what so ever regarding the actual design and composition of the so-called thermo battery. In essence, WO96/04522 suggests the general use of electrolytic power sources as an alternative to e.g. piezo-electric power sources. A similar approach is described in US 5133257 wherein heat generated by the detonating fuse is used to melt down and thereby start current emission from an electrolyte, which only emits current when in a molten state. However, neither WO96/04522, nor US 51332557 describes the power source in any detail. Nonetheless, it can be understood that the power source should comprise an electrolytic element placed next to the fuse and having two wires connected to it forming the contacts to loop with the rest of the electrical circuit.

However, designs using conventional pyro battery approaches have been investigated and found not to meet the requirements put on next generation pyro-electronic detonators. Basically, they cannot provide accurate and rapid enough electrical energy responses to the fuse signal.

Summary of the invention

In order to provide for pyro-electronic detonators having improved delay accuracy there is thus a need for an improved heat activated power source. The invention is based on the insight that certain requirements should be

met by such a power source, as summarized in the following:

- No fortuitous activation; the activating temperature of the power source should not be lower than 200°C – 250°C, which corresponds to the ignition temperature of PETN (Pentaerythritol tetranitrate, a very powerful explosive agent commonly used as detonator charge in detonators). This requirement is found important in order to meet specified safety standards and implicates that the power source must not activate by temperatures below the critical activation temperature of the detonator charge. At temperatures above that limit, the detonator charge will obviously self-detonate anyway.

- Reliable and instantaneous performance; the voltage should increase up to a specified working voltage (e.g. 1 V) in a short period of time, preferably in less than 10 ms. This time period, increased with any time delays from the electronic delay circuitry, dictates the shortest time delay possible for the detonator.

- The maximum time deviation in outputting the working voltage (the delay accuracy) should be low since the time deviations from the respective elements in the detonator will add up to a total time deviation defining the overall accuracy of the detonator. Preferably the time deviation should be as low as +/- 1 ms.

- Storage ability – assembled power sources should withstand all standard storage tests, without loss of function.

-Ease of manufacturing using conventional manufacturing equipment for pressing and assembling of conventional pyrotechnical delay elements, without need for inert gas conditions.

The requirements obviously have to be fulfilled throughout the whole range of working temperatures for the detonator, e.g. -40°C to +70°C.

The first requirement disallows the use of well-known and functional batteries with liquid and dry

(gelled) electrolytes, since they are active already at room temperature.

The second requirement states that the activation time must be very short. Authors of previous descriptions regarding conventional pyro-batteries either skip this question completely, or accept time deviations greatly exceeding the desired maximum of 10 ms.

Known pyro-batteries have, in fact, been used for applications totally different from detonators. Thus, the prior art pyro-batteries are obviously not capable of meeting the above-defined requirements for improved detonator performance.

Hence, there is a need for improved heat activated power sources, as well as for pyro-electronic detonators comprising such a power source and thus providing the desired delay time accuracy. The improved heat activated power source, and the detonators, should furthermore be easily reproducible on a large scale with maintained performance.

Based on the above insights by the inventors, and in order to meet the specified requirements, a novel heat activated power source is suggested. Hence, according to one aspect of the present invention, a heat activated power source is provided which comprises an electrically conductive shell extended along a longitudinal axis, an anode element, a heat activated electrolyte element, and a cathode element. The anode element, the electrolyte element, and the cathode element are stacked in said order along said longitudinal axis in said shell, and as a whole form an unitary body. The heat activated electrolyte element is switchable from an ion-isolative ground state to an ion-conductive active state by means of a heat energy pulse exceeding a threshold energy level. A first element of said anode and cathode elements serves as an electrode element that is electrically insulated from the shell, and a second element of said anode and cathode elements is electrically interconnected

with the shell and comprises a heat energy amplifying material. The electrical insulation can, for example, be provided by an electrically insulating sleeve separating the first element from the shell. The heat energy amplifying material is operative to ignite in response to a heat energy signal lower than said threshold energy level and, when ignited, to provide said electrolyte element with a heat energy pulse exceeding said threshold energy level. The second (heat energy amplifying) element thus serves the double purposes of taking part in the electrochemical process that generates the electrical energy and of amplifying an otherwise too small heat energy signal so that the resulting heat energy is enough to activate the electrolyte element. Thereby the first (electrode) element and the shell form two terminals between which a voltage is supplied when a heat energy signal lower than said threshold energy level is received by the second element which then amplifies the energy signal and activates the electrolyte element.

One straightforward way of reducing the heat energy needed to activate the electrolyte is to choose an electrolyte compound that is activated already at low temperatures. However, such a solution is not possible for reasons of safety. In fact, there is an inevitable tradeoff between activation accuracy at one hand (driven by low activation temperatures) and safety at the other hand (driven by the desired need for a substantial amount of heat energy to activate the electrolyte). To this end, the provision of a heat energy amplifying element is found to reduce the activation time vastly. The heat amplifying material can be chosen such that it responds to a very small amount of heat energy, typically a spark or a very limited detonation (e.g. from a shock tube such as NONEL®, available from Dyno Nobel), that does not provide enough energy to substantially heat any of the elements but that instead ignites the heat amplifying

material whereby the second element provides an amount of heat energy that is sufficient to activate the electrolyte element. The second element thus acts as a heat energy amplifier between the heat signal that activates the power source and the actual activation of the electrolyte element. In effect, the heat activated power source defines two ends, one end in which the first (electrode) element resides and in which the voltage is supplied via the electrode element and the electrically conductive shell, and an opposite end in which the second (heat amplifying) element resides and which end is responsive to and amplifies an external heat energy signal that is lower than the threshold energy level.

The energy amplification provides for vastly reduced activation times compared to prior devices. Hence, the use of a heat amplifying element as such is beneficial. However, the activation time is further reduced by the compact design resulting from the combined electrochemical and heat energy amplifying properties provided for by the second element. According to the present invention, it is thus furthermore realized that a heat energy amplifying element and one of the anode and cathode elements can be incorporated into one single element, forming the above said second element. Thereby, the heat activated power source supplies electrical energy as soon as the heat energy signal amplified by the second element is intensive enough, which for many compound compositions is virtually immediate (typically within less that 3 ms).

The heat activated electrolyte element transmits ions only when heated above a certain temperature. The threshold energy needed to activate the electrolyte element thus equals the heat energy needed to increase the temperature of the electrolyte element from its initial temperature to the activation temperature. The actual amount of energy needed for this temperature

increase obviously depends on the volume and heat capacity of the electrolyte element.

In other words, the threshold energy for activating the electrolyte element indeed depends on the particular choice of electrolyte compound and the volume thereof but it also depends on the initial temperature of the electrolyte. Obviously, a larger amount of energy is needed if the electrolyte is very cold than if it is warm. However, the power source should preferably be able to operate in temperatures between -40°C and +70°C, and the energy amplification should therefore be enough even if the electrolyte initially is -40°C cold.

In order to minimize the time between receiving the initial initiation signal (the heat energy signal) and supplying an electrical voltage, the respective elements should have small volumes and large interfacing surfaces. The total heat energy needed to activate the electrolyte is thereby minimized due to the small volume and the speed of the heat energy transfer is maximized due to the large heat exposed areas. Large interfacing areas furthermore accelerate the electrochemical process since it is based on ion exchange between the respective elements. For this reason thin circular segments are found to be the most efficient shapes for the respective elements, and the shell is therefore preferably cylindrical. Furthermore, the anode element, the electrolyte element, and the cathode element are stacked in direct contact with each other and together form an unitary body. Thereby the interface areas and thus the heat transfer between the respective elements are maximized.

Depending on the application at hand, either the cathode element or the anode element can be used as heat energy amplifying element. Thus, according to one embodiment, the cathode element serves as the second, (heat amplifying) element and the anode element serves as

the first (electrode) element. However, the reverse configuration is found to provide even higher voltages for many material compositions. Thus, according to another embodiment, the anode element serves as the second (heat amplifying) element and the cathode element serves as the first (electrode) element.

For example, in a detonator application, the second heat energy amplifying element typically receives a heat energy signal from a shock tube. A shock tube signal is enough to activate the power source according to the present invention even though the signal is quite minute, since the signal need not activate the heat activated electrolyte by itself. Instead, the shock tube signal need only initiate (i.e. ignite) the heat amplifying element which in turn provides the considerable heat energy signal that is needed in order to facilitate short enough delay times (i.e. rapid enough heating of the electrolyte element).

According to one embodiment, the second element additionally comprises an ionically active material other than the heat energy amplifying material. The second element thus comprises two materials, one material that is ionically active and that participates in the electrolytic process and one material that provides for the heat amplifying property. In such case it is important for the two materials to be well integrated into an unitary element in order to promote heat transport to the heat activated electrolyte element. This embodiment is advantageous in that the respective materials can be optimized for their respective function. The ionically active material is preferably arranged facing the electrolyte element and the heat amplifying material might then be arranged facing the opposite side of the element which is thus responsive to a heat initiation signal.

However, the use of two materials might restrain the initiation speed, since the heat emitted by the heat amplifying material must first travel through the ionically active material before reaching the electrolyte element. Therefore, according to another embodiment the second element comprises one material only which is both heat amplifying and ionically active. This is advantageous since the second element can then be made more compact, and since the emitted heat hit the electrolyte element directly.

In case the second element comprises one material only, the element is preferably between 2 mm and 5 mm thick, and is most preferably about 3 mm thick. In case the second element comprises an ionically active material and a heat amplifying material, these are preferably arranged in separate layers as described above. The heat amplifying layer is then preferably between 2 mm and 5 mm, and is most preferably about 3 mm thick, whereas the ionically active layer is preferably between 0.1 mm and 3 mm and is most preferably about 0.3 mm thick (which typically is a convenient minimum thickness for ease of manufacturing).

The first of said anode and cathode elements should preferably be between 0.1 mm and 5 mm thick, and most preferably about 3 mm.

According to one embodiment of the invention, the cathode element comprises a compound that is chosen from the group consisting of tungsten, molybdenum, tin, lead, platinum, palladium, silver, and gold. The compound forming the cathode is preferably in the form of compressed powder.

According to one embodiment of the invention, the anode element comprises a compound that is chosen from the group consisting of: aluminum, zinc, magnesium, and iron. The compound forming the anode element is preferably in the form of compressed powder. However, the

anode element could alternatively be formed out of a solid body, e.g. a foil or a disc.

The electrolyte should preferably have a rapid and distinct switching behavior from the ion-isolative state to the ion-conductive state. The rapidness is obviously needed in order to keep down the delay times (in effect, the time it takes to activate the power source), but the distinctness is equally crucial in order to provide for the required time accuracy. Hence, according to one embodiment of the present invention, the heat activated electrolytic element comprises a compound that is chosen from the group consisting of $LiAlCl_4$, $LiBF_4$, LiCl, and LiBr. These compounds are found to be particularly successful in providing for rapid and accurate activation processes, i.e. they rapidly and distinctly switches from the ion-isolative state to the ion-conducting state. Independent from the particular choice of compound, the compound preferably is a granulated compound or a compound in a crystalline or polycrystalline state.

Regardless of which particular compound that is chosen for the electrolyte element, the electrolyte should preferably exhibit a negative temperature coefficient of ion resistance as well as abrupt increase of ion conductivity (switching-over), most preferably in the temperature range of 200°C - 250°C.

The electrolyte element should preferably be as thin as possible in order to minimize the heat response time. However, manufacturing conditions might restricts the design of the electrolyte element. In one particular embodiment, the electrolyte element is typically about 0.3 mm thick.

According to one embodiment, the electrolyte element must have a temperature above 200°C and preferably above 250°C in order to change state from said ion-isolative ground state to said ion-conductive active state. The threshold energy level is then the amount of heat energy

needed to heat the electrolyte element from its initial temperature to 200°C or 250°C, respectively. In case the power source is used in a detonator, this temperature is normally high enough not to affect the safety regulations regarding the detonator since the detonator typically comprises a detonator charge which self-detonates at these temperatures.

The above defined requirements for detonator power sources are desirable not only for detonator applications, but also for a range of other applications. Examples of such alternative applications might include fire alarms, space shuttles, power reserves etc. It is thus realized that power sources fulfilling the above requirements will find alternative uses in addition to detonators, and any such alternative use is thus within the scope of the present invention. However, it should be noted that the requirements put on the heat activated power source according to the present invention are very specific and are not nearly met by prior art power sources used for other applications. In effect, the power source according to the present invention actually provides new possibilities not only for detonator applications but also for a range of other applications.

Hence, the heat activated power source according to the present invention can be used for many different applications. Depending on the application at hand, the heat signal to which the second, heat amplifying element is responsive (i.e. the heat signal that ignites the heat amplifying element) can have many different origins. For example, if the inventive power source is used in a fire alarm an increased ambient temperature in case of fire generates a sufficient heat signal. However, in case the power source is used in a pyro-electronic detonator, the initiating heat energy signal is typically generated by a shock tube or similar. Thus, according to still one

embodiment, the amplifying element is operative to ignite by a heat energy signal supplied from a shock tube.

As stated above, the heat activated power source according to the present invention is well suited for use in a detonator capsule. Hence, another aspect of the present invention provides a detonator that comprises a heat activated power source as described above, an electronic delay circuitry, and a detonating charge. The detonator is preferably of a type that is used for civil purposes in commercial blasting equipment. The electronic delay circuitry is operative to input electrical current from said power source and to output an electrical signal initiating said pyrotechnical detonator charge. Due to the performance of the inventive power source, such a detonator is capable of providing very accurate time delays ranging from a few milliseconds to tens of seconds.

The electrical signal supplied by the heat activated power source is thus processed in the electronic delay circuitry wherefrom a more or less delayed electrical initiation signal is outputted which initiates the detonator charge. To this end, according to one embodiment, the detonator further comprises an initiator that is operative to initiate said pyrotechnical detonator charge by means of said electrical initiation signal. The initiator can, for example, be a fuse head of some sort.

Depending on the particular application at hand, the heat activated power source might not be able to provide a current for the entire delay time of the detonator. Basically, a longer lifetime of the power source requires larger volumes and dimensions of the anode, electrolyte and cathode elements. As stated above, the dimensions are critical factors when reducing the activation time.

Consequently, it is quite often preferred to use a power source having a lifetime that is shorter than the desired delay time of the detonator. Therefore, according to one embodiment, the electronic delay circuitry comprises a capacitor that is operative to store electrical energy from the power source during a delay time of said electronic delay circuitry.

According to still one embodiment, the detonator further comprises a metallic capsule forming the shell of the power source and furthermore containing the electronic delay circuitry and the detonating charge. The metallic capsule thus serves as an electrical connector element between the second element of said power source and said electronic delay circuitry.

According to another aspect, the invention provides a detonator system that comprises an inventive detonator as defined above and a shock tube. The shock tube is interconnected with the inventive power source and is operative to ignite the second (heat amplifying) element.

A major advantage of the heat activated power source according to the present invention is that it provides for ease of manufacturing, for example using existing manufacturing equipment for manufacturing traditional pyrotechnical detonators. Thus, according to one aspect of the present invention, a method of manufacturing a heat activated power source as described above is provided. According to this method, each of the first element, the second element, and the electrolyte element is separately pressed into the shell. Depending on the materials used, these manufacturing steps can typically be performed without need for inert gas conditions. In case the respective materials are granulated or in the form of a powder, each material is typically dosaged and poured into the shell before compressing it to a

compressed element forming part of the unitary anode/electrolyte/cathode-body.

In case the power source is to be used in a detonator, it might be manufactured directly in the detonator capsule.

Brief description of the drawings

The invention will now be described in detail with reference to the accompanying, exemplifying drawings on which:

Figure 1 illustrates a cross-section of a first embodiment of the heat activated power source according to the present invention.

Figure 2 illustrates a cross-section of a second embodiment of the heat activated power source according to the present invention.

Figure 3 illustrates a cross-section of an embodiment of a detonator comprising a heat activated power source according to the present invention.

Detailed description of the invention

Examples of compounds that could potentially be used in the heat activated electrolyte include salts such as $BaSO_4$, Li_2SO_4, $LiBF_4$, $LiAlCl_4$, $NaBF_4$, KCl, NaCl, LiCl, AlCl, ZnCl, LiF, LiBr; ammonium compounds such as NH_4Cl, $(NH_4)_2SO_4$, $AlNH_4(SO_4)_2$, organic compounds such as lithium formate $LiOOCH \cdot H_2O$, polyethylene oxide etc. However, $LiAlCl_4$, $LiBF_4$, LiCl, and LiBr are so far found to be most promising for meeting the activation speed requirements. However, it should be realized that any conventional or novel heat activated electrolyte possessing abrupt increase of conductivity (switching-over) in the temperature range of 200°C - 250°C can be used of the purpose of the present invention.

Depending on the electronic circuitry used in the delay unit of the inventive detonator, the voltage might have to be maintained for the entire delay time.

Alternatively the circuitry might be equipped with a capacitor, thus allowing the use of shorter voltage pulses which can be stored in the capacitor. The use of capacitors removes the requirements on the power source to output a current during the entire delay time, and thus ease the design specification.

One possible embodiment of the power source according to the present invention is shown in Figure 1. According to this embodiment, the power source 100 is fitted in a detonator and uses the metallic detonator capsule as shell 108. In effect, the power source forms an integral part of the detonator. Thus, the power source according to this embodiment comprises a metallic shell 108, forming an integral part of the detonator, an anode element 102 constituted by a pyrotechnical composition (e.g. $Fe_n O_m$/Al) pressed into an aluminum cup 101. The pyrotechnical composition according to this embodiment serves both as a heat amplifying element and as an ionically active portion of the anode element. According to one particular embodiment, Iron-aluminum thermite with a surplus of aluminum and the formula $[30\%Al/70\%Fe_2O_3] + 70\%Al_{20}$ is used in the anode element 102. The Al_{20} compound is basically an aluminum powder with a particle size of about 20 μm, and is commercially available from e.g. ALFA AESAR. The burning rate of 3 mm of such anode compound is approximately 20 +/- 1 ms, after which a heat shock wave is put upon the electrolyte element 104. The power source furthermore comprises a cathode element 105 and an electrolyte element 104. The cathode element is pressed into a plastic, electrically insulating tube 107, and the complete power source is stacked in the metallic shell 108. According to this embodiment, the cathode element 105 is formed by tungsten powder pressed into the plastic tube 107. Upon heating, the electrolyte element ionizes and the power source passes on to an active state in 7 - 8 ms whereby an electric voltage 106 is supplied between the metallic

shell and the cathode (i.e. the electrode) element. Thus, in this embodiment the anode element is used as heat amplifying element and is formed out of one single portion.

However, Figure 2 illustrates a second embodiment of the heat initiated power source wherein the heat amplifying element comprises two separate portions, an ionically active portion 203 and a heat energy amplifying portion 202. According to this particular embodiment, the power source resides in a metallic shell 201 and comprises an anode element 202, 203, an electrolyte element 204, and a cathode element 205. The cathode element is pressed into a plastic tube 207.

The anode element thus comprises two materials: an ionically active material 203 and an ignition material 202. The ignition material 202 is preferably composed of some pyrotechnical composition that exhibits a high precision burning rate. This can be provided, for example, by suitable choice of compressed powder, such as Pb_3O_4/Si, Bi_2O_3/Si etc. The ionically active material 203 is preferably constituted by a powder, plate, wafer, or disc etc. formed out of a metal such as aluminum, zinc, magnesium or iron. The heat activated power source is thus operative to supply a voltage 206 between the cathode element (i.e. the electrode element) and the shell.

The electrolyte element 104, 204 might be such that it melts when switching from the ion-isolative state to the ion-conducting state, or it might be of some other type. However, it is important that the material becomes active (i.e. starts conducting ions) within very short time interval (preferably within 3 ms) after receiving the heat energy pulse from the anode element. The cathode element is preferably, just like the anode element, constituted by a powder, plate, wafer, or disc formed out of metal. Preferably the metal is one of the following:

tungsten, molybdenum, tin, lead, platinum, palladium, silver, or gold.

The heat activated power source is preferrably cylindrical in shape, this is advatageous both from a manufacturing point of view and for maximizing the interface surfaces between the respective elements. In the above embodiments, the dimensions of the power source is typically somewhere between 3 mm and 20 mm in diameter and between 5 mm and 20 mm in length.

Figure 3 illustrates a complete detonator capsule 300 comprising a shock tube 301, a shock tube plug 302, a metallic, cylindrical capsule 303, and a heat activated power source 304 according to the present invention. The two polarities of the power source 304 is electrically interconnected with a delay circuitry directly via the electrode element 307 of the power source and via the capsule 303, respectively. Consequently there is no need for aditional wiring in the capsule. The capsule furtermore comprises an electronic delay circuitry 305 , for providing the desired delay time, a fuse head 306, and a detonator charge 307. In effect, the inventive detonator can be designed so that it appears and operates in the same way as purely pyrotechnical detonators. Thereby it can be operated by any person trained on such purely pyrotechnical detonators without any additional instructions.

The inventive heat activated power source can be manufactured using conventional manufacturing equipment. Manufacturing typically includes a number of dosaging and pressing cycles, during which the repsective ingredients are first dosaged and then pressed into the capsule. Since the heat activated power source according to the present invention does not require any wiring, but instead uses the capsule (or shell) as an electric conductor, the prior art manufacturing steps of providing

these wires in accurate positions in the power source is eliminated. Furthermore, unlike many prior art powers sources, there is no nead for inert gas conditions since all of the manufacturing steps can be performed in normal room conditions.

In essence, the present invention provides a heat activated power source that comprises an anode element, a cathode element, and an electrolyte element, all of which are stacked in an electrically conductive shell so as to form a unitary body therein. The electrolyte is of a type that is ionically passive below a certain temperature and that is ionically active above that temperature. One of the anode and cathode elements serves the additional purpose of providing for heat amplification, and thus amplifies an otherwise too small heat energy signal so that it is enough for activating the electrolyte. The power source is particularly suitable for use in pyro-electric detonator applications, where it facilitates highly accurate delay times that are virtually independent of the delay time duration. The power source is suitable for large scale manufacturing, with maintained time delay performance and without need for special manufacturing equipment or for inert gas conditions.